# QUALITY OF SERVICE OF WIRELESS OPTICAL NETWORKS

*A Thesis*

*Submitted in partial fulfillment*

*of the requirements for the degree of*

**Master of Technology**

in

**Communication and Networks**

*by*


**Venkatesh G**

(Roll No: 212EC5205)


*Under the guidance of*

**Prof. Santos Kumar Das**


Department of Electronics & Communication Engineering

National Institute of Technology Rourkela

Rourkela-769008, Odisha, India


2014

Dept. Electronics and Communication Engineering

# National Institute of Technology

# Rourkela

## CERTIFICATE

*This is to certify that the thesis entitled*, "**QUALITY OF SERVICE OF WIRELESS OPTICAL NETWORKS"** *submitted by* VENKATESH GUNDETI *in partial fulfillment of the requirements for the award of Master of Technology degree in* **Electronics and Communication Engineering** *with specialization in* "**Communication and Networks**" *during session 2013-2014 at National Institute of Technology, Rourkela and is an authentic work by him under my supervision and guidance.*

*To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.*

Place: Rourkela

Date: 27/05/2014

Prof. Santos Kumar Das
Department of ECE
National Institute of Technology
Rourkela-769008
Email: dassk@nitrkl.ac.in

# ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my guide Prof. Santos Kumar Das for his guidance, advice and constant support throughout my thesis work. As my supervisor, he has constantly encouraged me to remain focused on achieving my goal. His observations and comments helped me to establish the overall direction of the research and to move forward with investigation in depth. He has helped me greatly and been a source of knowledge. I would like to thank him for being my advisor here at National Institute of Technology, Rourkela.

I am also thankful to all the professors of the department for their support and encouragement. I would like to thank administrative and technical staff members of the Department who have been kind enough to advise and help in their respective roles. I am really thankful to my all friends. They made my days spent in this college so memorable and colorful.

I would conclude with my deepest gratitude to my parents and all my loved ones. Their blessings and moral support were always with me during all stages of my academic life. This thesis is a dedication to them who did not forget to keep me in their hearts when I could not be beside them.

VENKATESH GUNDETI

Roll No: 212EC205

Dept. of ECE

NIT, Rourkela

# ABSTRACT

Quality of Service (QoS) aplomb for network service provider over wireless optical network, which is a challenging factors for communication network applications. The next-generations, communication networks are directed at aiding various purposes such as data, voice and hypermedia over PS networks. In these systems, point-to-point correspondence might be upgraded with feature and high caliber of pictures. Also the access to data and administrations on private and open systems will be prevalent by higher information rates, nature of administration (QoS), efforts to establish safety, area mindfulness and new adaptable correspondence proficiencies. These characteristics will make new business open doors for producers and administrators, as well as for administrations suppliers utilizing these systems.

In this project, it is considered that source of communication systems are optical routers, where the data is transmitted via wireless channel to obtain possible assets in transmitting data from a source to destination. The service parameters such as the latency and blocking probability of the designed wireless optical network are analyzed by simulation.

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# Chapter 1
# Introduction

## 1.1 Objective and Inspiration

### 1.1.1 Objective

The main objective of this thesis is to find the quality service parameters of wireless optical network like latency and blocking probability of the data transmission. For designed wireless optical network, using the routing algorithms, delay queuing models and theory of blocking probability the parameters has been calculated. Blocking probability and delay for the network are simulated and results are presented.

### 1.1.2 Inspiration

In present days communication has become an important aspect for everyone. Optical networks provides good quality of service for communication between the several peers. From past few years communication has been going on fiber optical transmission of data which evolved very vigorously. For large distance communications optical fiber is the best option for data transmission and it is increasing day by day. Overall 80 percent of the communication for long distance are going on with optical systems. Since these optical communication will produce a good quality of service for data communication with any delay, jitter and loss rate, these are very fast for communications. For small distance communications installation the optical network is somewhat difficult or congested, for this purpose wireless optical systems can be used for certain range of kilometers. For communication within certain area these systems can be used for data transmission with higher data rates where delay, loss rate and jitter and probability of blocking of data are some of the important parameters has to be considered for communication.

## 1.2 Literature survey

Deva K B, Anthony C B, Christopher C D, Steve H and Konstantinos Y [1], article gives us the overview of the optical wireless communications system which operate in long and short range distances. In this paper they discussed the personal communication systems of point-point systems. The system reliability can be improved by crossing of the radio frequency and optical wireless systems with an extra RF link.

Ranjan, Nikhil, and Garima Krishna [2], describes the analysis of the wireless sensor network and with quality of service parameters on the basis of their transfer rate of data, delay and throughput. Mostly these networks are operated in terms of efficiency, computation power, memory and communication capabilities. Congestion control mechanism has been used for good design of the network.

Reaz, Abu Sayeem, Vishwanath Ramamurthi, Suman Sarkar, Dipak Ghosal, Sudhir Dixit, and Biswanath Mukherjee [3], defines a routing algorithm called DARA for wireless optical broadband access network. Admission control schemes has been provided by the authors for QoS requirements in Packet transmission. We have studied their algorithm used some way of their algorithm.

Singh, Manish [4], has computational and selection path algorithms for the various network services for QoS problems. In this they has estimated optimal path that satisfy the QoS parameters like jitter, bandwidth and delay. Network load balance and utilization of bandwidth has made them to choose the path among the feasible paths.

Luo, Yuanqiu, Ting Wang, Steve Weinstein, Milorad Cvijetic, and Shinya Nakamura [6], in this paper they have described the benefits of combining the wireless and optical fibers integrations methods for access networks. Their work results that the complexity of the access point decreases and capacity of the wireless network increases with the integration of optical wireless network.

Nema, Shikha, and Beena R. Ballal [7], explains the several advances in the fiber optical wireless communications in indoor. This paper introduces a nitty gritty survey of late advancements in adjustment plans, transmitter and recipient areas which will empower the acknowledgment of future superior and practical indoor optical remote frameworks. Discussed issues with the indoor wireless optical network that they offer less multipath dispersion and produces paths loss is lower.

Davis, Christopher C., Igor I. Smolyaninov, and Stuart D. Milner [8], in this papers they deals with significance of the first mile problem for broadband communication. Wireless optical has an impressive solution for the first mile problem. They have used the wireless optical as complement to radio frequency wireless systems such they can made highly direction for broadcasting and explained the flexible access of the optical wireless network.

## 1.3 Outline of Thesis

The entire thesis is divided into five sections which are concisely revealed below.

Chapter 1: Introduction

Chapter 2: Wireless Optical Communication, which gives overview of the optical network, wireless optical system, optical transmitters and receivers, optical amplifiers and wireless optical channel.

Chapter 3: Quality of service parameters which gives brief introduction about service parameters like delay, loss and other parameters of network performance and QoS, Scheduling and Queuing management schemes, Queuing Delay model, Little theorem and Blocking probability.

Chapter 4: Designing of Network and simulation, which gives the topology of the network used for purpose of simulation and results of simulations are presented.

Chapter 5: Conclusion and future work, which gives you the complete conclusion of project work along with its future approaching.

# Chapter 2

# Wireless Optical Communications

## 2.1 Optical Networks

A very thin glass cylinders that carry in the form of light signals are Optical fiber. Generally, the data stored in any device establishes connection using optical fibers to an optical network. These networks comprises optical devices to produce the optical signals from electrical signals to enable the communication of data. These optical signals renovate and transmits via fibers and pass the signals through optical network.

Optical fiber consists of two concentric glass layers (shown in figure 1), the inner core and the outer clad with a lower refraction index. A third protective layer, buffer coating, is applied as the materials and protects the optical fiber especially against the moisture and abrasion, which might degrade the fiber.

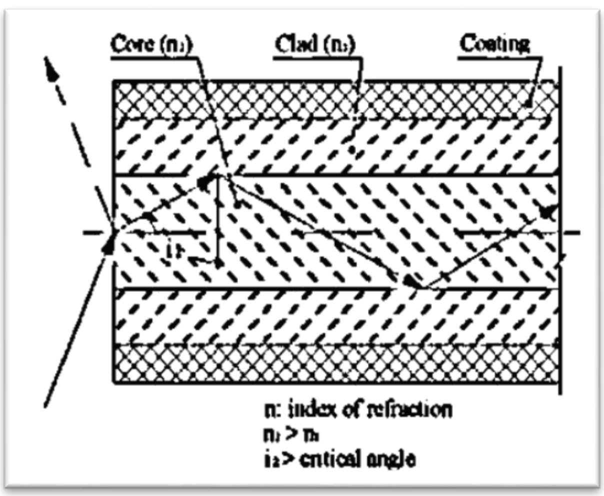


**Fig 2. 1: Optical Fiber.**

Optical fibers which have higher bandwidth and are less liable to electromagnetic interferences and awful effects. Hence these are chosen for data transmission above bit of tens of megabits per second above a kilometer distance. Short distance realizing (a few meters to hundreds of meters), high speed data transmission in large interconnection systems (gigabits per second and above) are chosen in optical fibers. Theoretically, it is possible to send data in a single fiber at a rate of 50 tera-bits per second. Optical Networks of first generation are works simply by optical fibers replacing the copper wires.

Despite, there are some dissimilarities among the fiber and copper as communicated media:

- Optical network resources are to be optimized because as compare to electronic devices, the optical devices are more affluent.
- The data processing lead into electronic circuits are far less rate than the rate at which optical signals are processed.
- A carrier with different wavelengths of number of optical signals are at the same time passed through the same fiber.

## 2.2 Wireless Optical System

For the future compeers, wireless network facilities might be given by Millimeter wave radio get to in altered access and versatile requisitions. In such frameworks, the rate of recurrence of radio (i.e., RF) signals could be created at a primary station which can bolstered through optical fiber communications to antenna sites. Such that straight forward radio base stations which are executed could be empowered by the distribution system of optics. We will accordingly examine the adjusted remote correspondence systems with optical fiber as feeder system for up degree of existing remote system, which are equipped for supporting information rates in the order of Gbps. In remote environment multipath delay and fading in signals where single bearer versatile correspondence frameworks don't perform well. In such frameworks ISI and blurring in indicator plentifulness happens, multipath impacts because of the recurrence selectivity of the channel shows up at the beneficiary side. So, the overall performance of the system becomes poor due to high probability of errors. These errors are rectified by using the adaptive equalization and channel coding techniques. However, due to the inherent delay in the coding and equalization process and high cost of the hardware, it is quite difficult to use these techniques in systems operating at high bit rates, for example, up to several Mbps.

Communication model for a wireless optical system is shown in the figure 2.2. Required information or data transmitted where the transmitters are of optical transmitters and then they are modulated for the signal transmission which is fed to wireless medium and then led for the transmission. Detector part consist of the optical receivers which are then converted and the transmitted data is obtained.

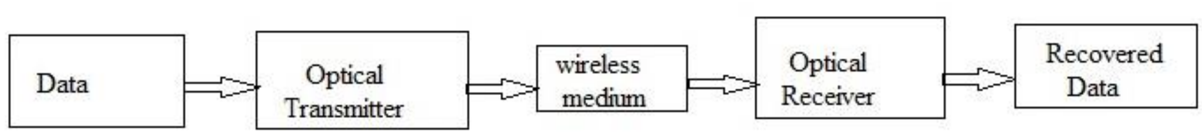


**Fig 2. 2: Communication model of Wireless Optical Link.**

## 2.2.1 Optical transmitter

To understand the tunable optical transmitter we should have the background knowledge of basic principles of laser and operation of it. Laser amplification by stimulated emission of radiation which in short form called as “laser”. A high intense power beams of coherent light is generated by the laser by a process called stimulated emission. Figure shows the general structure of laser.

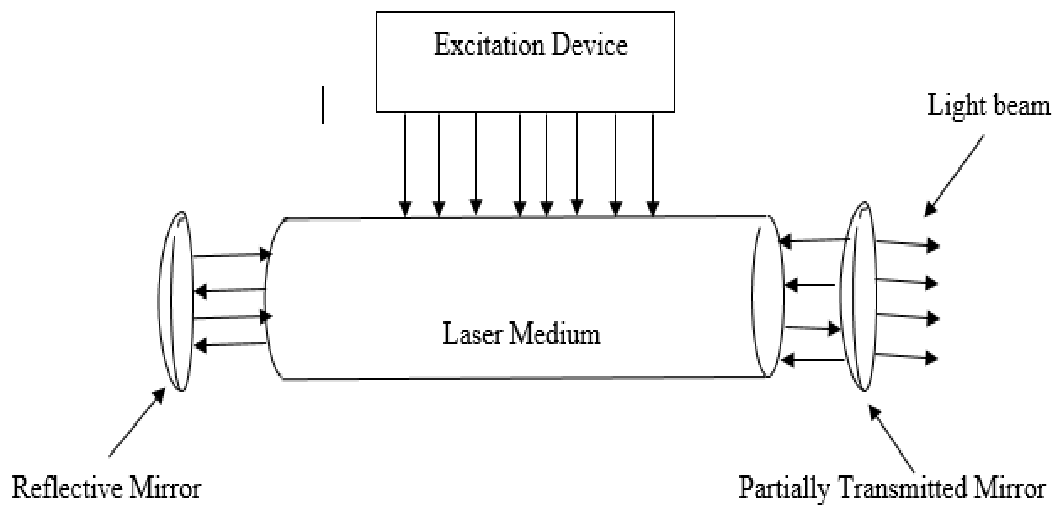


**Fig 2. 3: General Structure of Laser.**

Typically a laser contains two mirrors which form a cavity, an excitation device and a lasing medium that inhibits the cavity. A quasi stable substance of excitation device supplies current to lasing medium. Current applied to the lasing medium by excitation device makes the electrons excited which are present in it. A photon light is emitted when an electron drops from higher state to ground state such that the photon reflects from the mirrors at end of each cavity that will enter again into the medium.

Stimulated emission occurs only when photon enters closely to an electron that is excited. Energy will be released from that electron due to photon such that electron goes back to the ground state. Like this photons are produced by the electrons that will have same coherency and path as the stimulating photon. Light will build up in the cavity at required specified frequency as the frequency of the photon are integral part of length of cavity. In the meanwhile, energy is removed from the medium, as early as possible light intensity which is build up will be inserted between the stimulated and normal emission. Such that higher light intensities are created by the occurrence of stimulated emission then the photons are to and fro feed by the mirrors present in the cavity. Some of the photons will be disappeared from the cavity due to moderately transmitting by the one of the mirrors present. By varying the cavity length, emitted light frequency can be moderately attuned.

## 2.2.2 Laser with Semiconductor diode

Semiconductor diode laser are the frequently used laser in the optical networks. By acquiring the bulk laser diode, semiconductor diode can be easily realized, where the mirrored edges of p-n junction are perpendicular to the junction (see Fig). By the knowledge of the semiconductor physics, semiconductor diode operation can be easily understand.

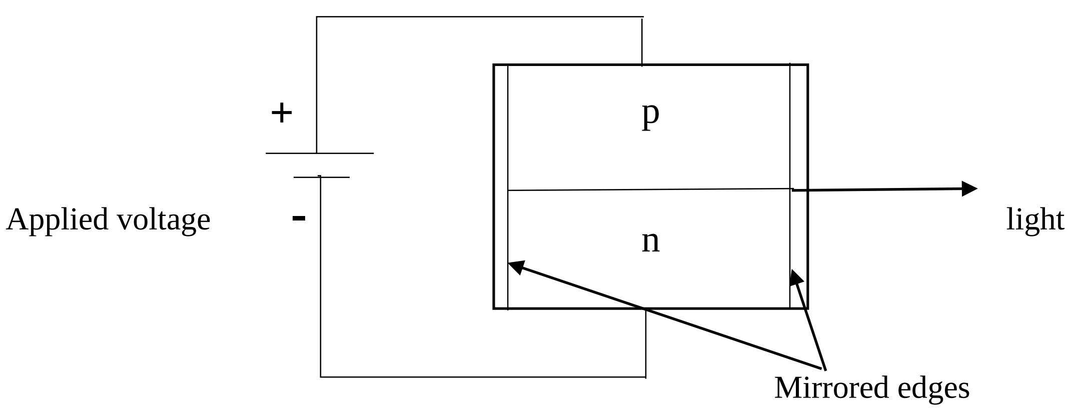


**Fig 2. 4: Semiconductor diode laser.**

When a voltage is applied to the p-n junction, stimulated emission process is started and the device is forward biased which cause the electrons in n-region will merge with holes in the p-region, which releases light energy whose frequency is allied with the band gap of the device. Different frequencies of light can be emitted with various kinds of semiconductor materials. The p-n junction whose edges are mirrored is perpendicular to length of the cavity concludes laser actually frequency of light that is emitted by it.

## 2.3 Optical Amplifiers

Optical signals that are transmitted in the optical fiber which propagate through the optical communication system are attenuated. Multiplexers and couplers are the other components of optical communication system which add losses to the system. The detection of signal is weak because due to the loss in strength of the signal after reached at some distance. For this reason the signal strength has to be restored which can be done by regenerating the signal, that is by retransmitting the received signal. This procedure is consummated by the regenerators.

Conversion of optical signal to electrical signal and alters back to optical signal for ahead of communication.

On other hand, amplifier are not most probably advised. Since they produce extra noise to the system where the signal is passed into the various amplifiers in the pathway of analog nature of the amplifier. In a system, the output power, transient nature of the amplifier and the spectral shape of the gain are significant deliberations. Preferably, it is considered that the output power must adequately high to come across requirements of the network applications. The gain should be uniform above the functioning wavelength range which is to be unaffected dissimilarities in the input signal power.

Optical amplifiers provides quite a lot of compensations over regenerators.

**Table 1: Difference between Optical amplifier and Regenerator.**

| Optical Amplifier | Regenerator |
|---|---|
| The power of the optical signal is increased. | It produces new signal. |
| Here signal is not converted electrical signal, Since the entire process is optical. | It is an O-E-O process i.e., the optical signal is converted to electrical and then to optical. The reason it involves electronics is that building an all optical generator capable of deciding what is signal and what is noise is difficult. It's a three stage process: 1) Reshaping = > O-E 2) Re-amplification => Optical 3) Retiming => O-E. |
| It amplifies the multiplexed signal together. | The data is operated only on single channel. |
| Frequency upgrade is not necessary in this. | Up-gradation of regenerator is necessary for high frequency. |
| It adds additional noise. | The noise is removed. |

Modulation method and bit rate used in the communication system of regenerators are exclusive whereas, in optical amplifiers bit rate and signal formats are impervious. Such that the system can be easily upgradable using the optical amplifiers whereas regenerators used in a system is upgrading by replacing all the regenerators.

Moreover, optical amplifiers ensure considerable large gain bandwidths, and as a significance, several WDM signals can be instantaneously amplify by a single amplifier whereas we need a regenerator for each wavelength. Therefore optical amplifiers have become essential components in optical communication systems for high-performance.

## 2.4 Applications of Optical Amplifier

### 2.4.1 In-line Optical Amplifier

Generally the signal goes through loss because of attenuation during a single mode glass fibre. Therefore regeneration of the signal and its amplification has to be done when a definite interval of time. Inline optical amplifier are often accustomed to compensate attenuation loss and to extend the gap between regenerative repeaters.

### 2.4.2 Preamplifier

Frequently, an optical amplifier is engaged as a front-end preamplifier beforehand an optical receiver. For instance to decrease the SNR degradation, the weak optical signals is intensified by the preamplifier and moreover preamplifier shows high gain and higher bandwidth.

### 2.4.3 Power Amplifier

Enhancing of the signals is concluded by the power or booster amplifiers placed merely next to the transmitter. Looking on the amplifier gain and fibre loss, the transmission distance may be multiplied by 10-100 km. Following fig shows Different applications of optical amplifier are shown in the figure 2.5.

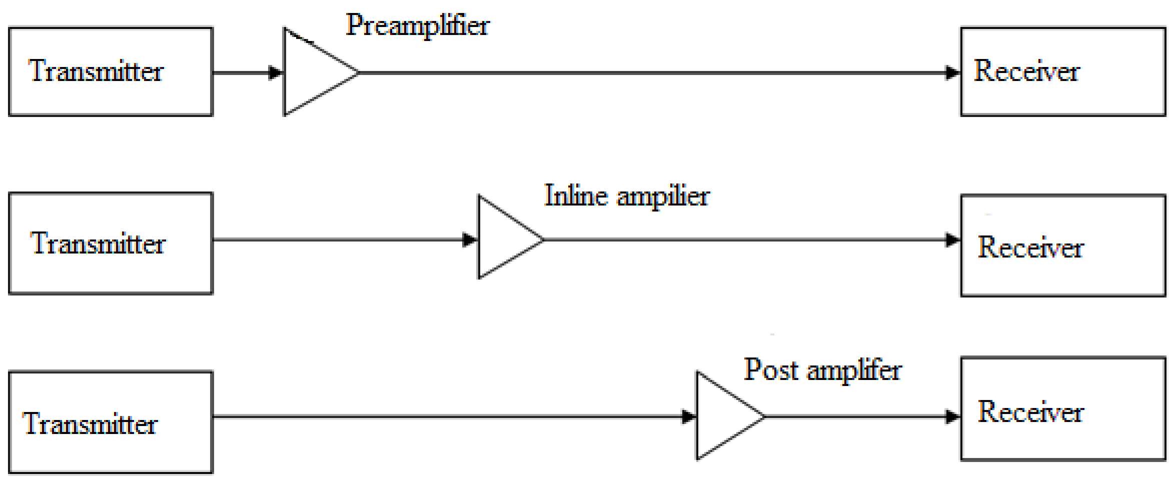


**Fig 2. 5: Block Diagram of different applications of optical amplifier.**

There are three different types of optical amplifiers:

- Erbium-doped fiber amplifiers
- Raman amplifiers
- Semiconductor amplifiers

Out these three amplifiers[11], erbium-doped fiber amplifier are efficiently using in the communication system.

## Erbium doped optical amplifiers

An erbium-doped fiber amplifier consists of a silica fiber of certain where the core is doped with ionized atoms (ions), Er3+, which is the rare earth element erbium. Usually, at a wavelength of 980 nm or 1480 nm, the fiber is pumped from a laser by using a pump signal. The wavelength-selective coupler is used after the doped fiber so that to get the output of the pump laser along with the input signal[11]. In case, to separate the amplified signal from the remaining pump signal power we can use wavelength-selective coupler at the output if necessary. To avoid the replications in the amplifier, either at input or output isolator is used.

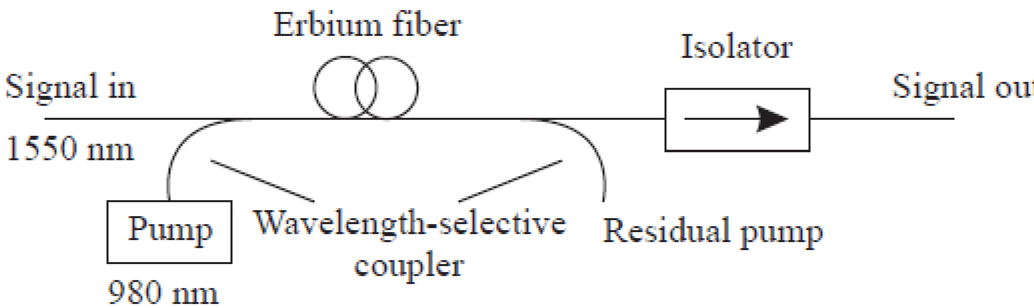


**Fig 2. 6: Erbium-doped fiber amplifier.**

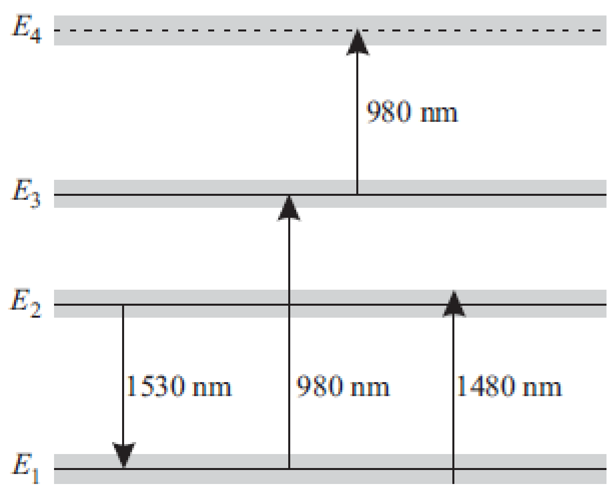


**Fig 2. 7: Energy level diagram of EDFA.**

From the above figure 2.7 it shows that they are three levels of energy E1, E2 and E3 of E3+ ion of silica glass. The E4 energy level is not present in the silica glass, it is present in Fluoride glass. Stark splitting is a process that spread the energy levels into bands. Ions jump into the higher energy level, which are excited by pumping with amplifier at wavelengths labelled at the difference between the energy levels. The transition gap between the energy levels E1 and E3 is 980nm.Similarly, the transition gap between E1 and E2 is 1480nm. Due to stimulated emission and spontaneous emission emitted photons with wavelengths are indicated with downward transition.

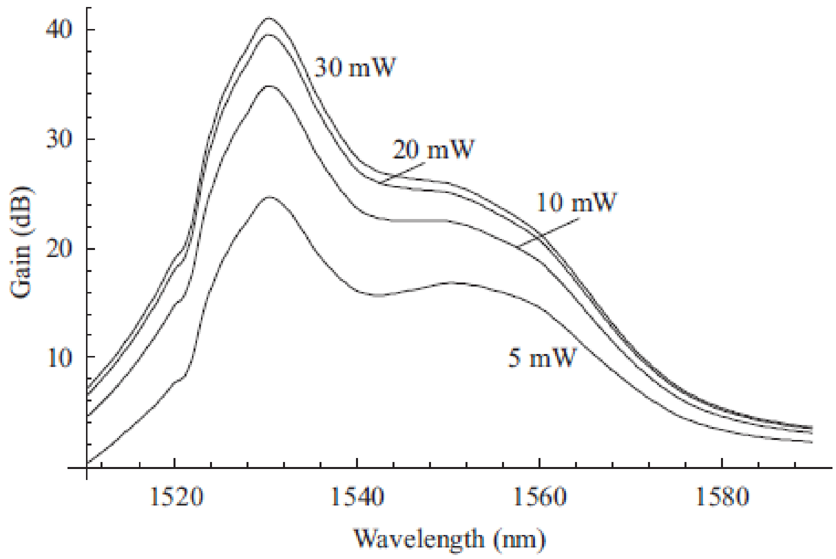


**Fig 2. 8: Typical EFDA gain plot.**

The above figure 2.8 shows the gain plot of EDFA with four pump power different values as a function of wavelength. Taking on the pumping, 15m to 980nm considered as a doped fiber length.

## 2.5 Optical Receiver

The direct detection of an optical receiver is shown in the Fig 2.9. The main purpose of the optical receiver is to retrieve the data which is transmitted in form of optical signal that is converted to electrical signal passed through single mode fiber of the receiver. The incoming optical signal is pre-amplified by the optical amplifier which is fed in to the optical filter to cut the noise level by selecting the desired wavelength channel of wavelength demultiplexer or by stimulated spontaneous emission. Optical signal is converted into electrical signal by the photo detector, led to post amplifier. An equalizer is used for compensating the intersymbol inference. To pull out the received signal, a recovery clock circuit is used in the decision circuit. A phase lock loop is used in the design of the recovery clock circuit. At last the sampled signal is compared with the pre-set threshold where the signal in binary form is led out by the decision circuit. Decision circuit sets the received signal sample to bit 1 or to bit 0 after comparing with threshold.

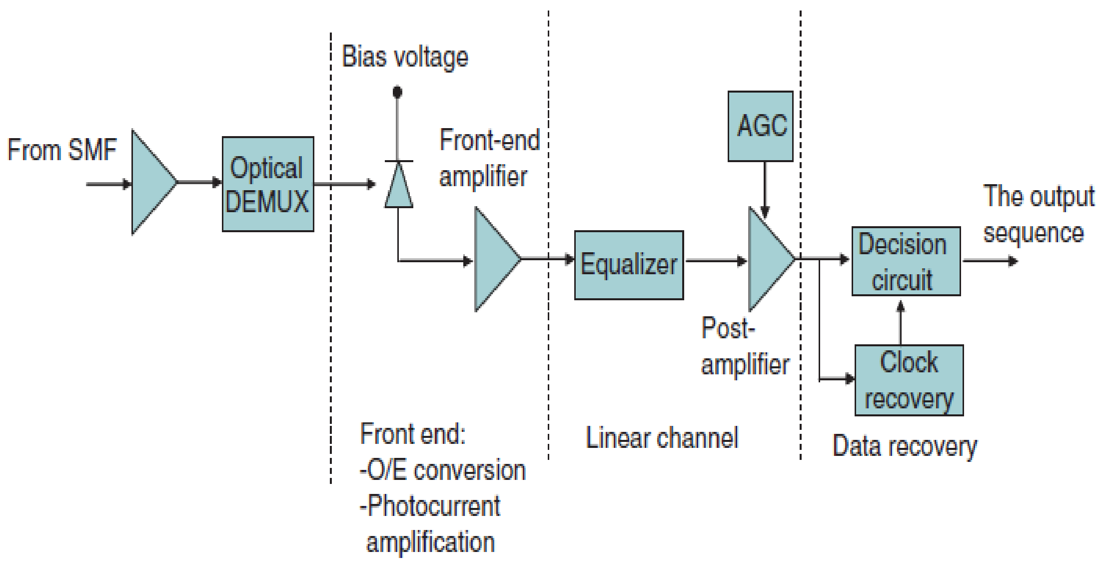


**Fig 2. 9: Block Diagram of Optical Receiver.**

Formerly being transmitted over the optical fiber, the optical indicator created by semiconductor laser must be tweaked by data sign. Normally for transmitters functioning at 10 Gb/s or more, the semiconductor laser diode (LD) is generally pre-disposition-ed at consistent present to give constant wave (CW) yield, and outside modulators are utilized to force the data sign to be transmitted. Most basic and prominent modulators utilized are electro-optic optical modulators, for example, Mach–zehnder modulators, and electro-absorption modulator.

## 2.6 Wireless Optical Channel

Wireless optical channels vary in numerous important techniques from communication channels canned expansively in collected works.

Optical channels are characterized as intensity modulated, direct detection channels. Fig 2.10 shows the Optical intensity modulated, direct-detection optical link. The power emitted per solid angle in watts per steroidal is called optical intensity. The information which is transmitted as electrical current signal is modulated by the instant optical intensity[12]. The data is directed as the optical waveform via the channel which doesn't enclose in the frequency, amplitude or phase but fairly in the intensity of the transferred signal. Now a day's optoelectronics will not work straightly on the phase or frequency in the range of 100GHz of optical signal. Optical intensity modulation is a process of conversion of electro optical signal which is generally consummate by laser diode or by light emitting diode which will operate at a wavelength range of 850-950nm.

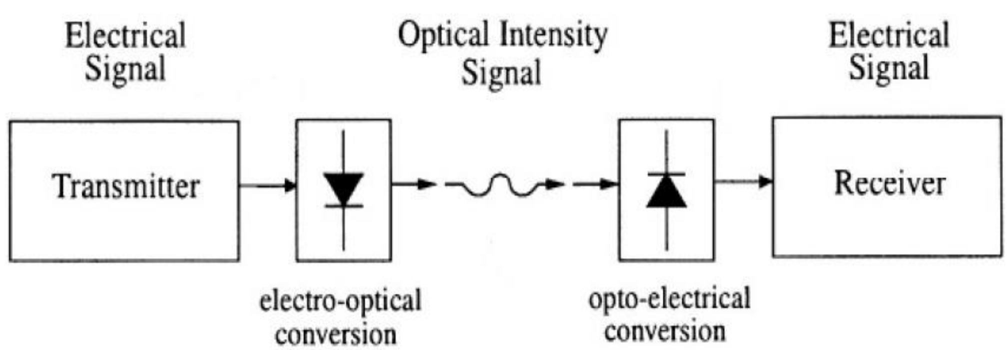


**Fig 2. 10: Optical intensity with direct detection in communication channel block diagram.**

Opto-electrical conversion is normally accomplished by silicon photodiode. The output electrical photocurrent is directly proportional to irradiance received which is obtained by photodiode which is in direct-detection of intensity signal of optical. The detector used in the figure is reverse biased diode. For calculating the intensity, transmitted signal which is in electromagnetic form is amplitude squared and integrated with the time variable. In the modulation method the average power transmitted must be further restricting than limitation sets of wavelength peak power. The optical wireless link where we use optical wavelength as an optimal has effects the allowable exposure limit.

# Chapter 3
# Quality of Service Parameters

## Introduction

The significance of network congestion management and Quality of Service makes the network builders to recognize the data loss, delay and its sensitivity has increased in these days. To reduce the delay, delay jitter and losses in packet became the major charge to build the buffer management tools for the network builders. It is requires to understand the traffic for building the network management tools. To sustain the capacity of the network maximum, QoS has to be complied with service provider of the network is possible only when the traffic modelling is made accurate by enhancing traffic resources. To provide the high critical QoS for the network and its traffic network model will have their impact on it.

Applications of real time have severe necessities for delay jitter, loss and delay. Quality of data near receiver is worse because of the delay in packet and loss in packets. In data transmission there will adverse gaps and interruption in data due losses in data packets. In real time applications, the data which is just arrived will overrides the previous data, where the loss of packet is comparably same as the packet large delay. The data retrieved at the receiver is damaged by the large jitter delay. Delay propagation and link error are some of the sources for the delay and loss of packets. In this we have focused only on the delay in data because of queuing in router and overflow of buffer. The interface among the network and traffic will be affected by the delay and loss in data for example congestion. Parameters of QoS and simulation analysis is explained.

## 3.1 Delay

Occurrence of delay is due to transmission of packet in router and waiting of packet in the barrier for the service. For service and queuing delay, we use the word queuing delay for both of them. Therefore, the at which the packets goes into the routers buffer up to the time it comes out of the router, this duration time is comparable same for queuing delay. There are two ways to for analyzing the delay, the delay pattern can be surveyed by its auto correlation function and its distribution. Delay auto correlation function is utilized for indication that how delay of packets will correlate for packets of sequence. Autocorrelation function is defined as

$$ACF(d,l) = \frac{\sum_{i=1}^{n-l}\left[(d_i - \mu_d)(d_{i+l} - \mu_d)\right]}{\sum_{i=1}^{n}(d_i - \mu_d)^2} \tag{3.1}$$

Where $n$ is the total number of packets measured, $\mu_d$ is the average packet delay, $d$ is the packet delay random variable, $d_i$ is the delay of the $i^{th}$ packet, $l$ is the lag of correlation.

Due to loss of packet, every time delay of the packet is not defined. In our study, the lost packet delay is not defined and is omitted from the delay autocorrelation and distribution function calculation. The omission of lost packets delay, we can take into count them as missing sample in measurement of delay.

## 3.2 Loss

The ratio of number of packets that are dropped totally to the number of packets that are input surrounded by a period of time.

$$loss\ rate = \frac{total\ number\ of\ dropped\ packets}{total\ number\ of\ input\ packets} \tag{3.2}$$

Loss rate is one of the network performance parameter- load of traffic that effects the rate of loss.

$$traffic\ load = \frac{total\ number\ of\ arrived\ packets}{total\ number\ of\ packets\ that\ can\ be\ transmitted} \tag{3.3}$$

Since rate of packet loss is one of the significant constraint, it will not satisfactorily capture the thorough pattern loss. Pattern losses are very dissimilar, for a same loss rate. In a network, to know how packets are dropped can be explored by inspecting the loss episode distribution. Specifically we use loss episode exploration for a particular data traffic basis, because real-time data solicitations are vulnerable to succeeding loss of packet than the intermittent single loss of packet.

## 3.3 Other parameters of network performance and QoS

Furthermore to delay and loss, we also examine the buffer tenancy probability (probabilities of buffer sizes) of the router, throughput per-flow, traffic load per-flow, and loss rate per-flow, where every one of them influence the arriving effects of traffic at the router and how it reacts to the traffic.

The probability of tenancy of buffer calculates frequent size of the buffer is equal to *i* packets, and which can be measured by calculating the changes in the buffer size. For *N* packets to be of maximum buffer size, there should be *N+1* states, where empty buffer resembles to state 0 and full buffer resembles to state *N*. At any time, if there is change in the state (buffer size) it is recorded. The probability of tenancy of buffer state *i* is then defined as

$$P(i) = \frac{total\ number\ of\ times\ state = i\ (buffer\ contains\ i\ packets)}{total\ number\ of\ state\,(occupancy)\ changes + 1} \tag{3.4}$$

The number of packets delivered by the router is routers throughput. In per flow throughput of every source packet traffic, it is easy to distinguish the exactness and enactment of altered queue and scheduling management systems, which can be defined as

$$TP_i = \frac{total\ number\ of\ packets\ from\ source\ i\ that\ are\ delivered}{total\ number\ of\ packets\ delivered} \tag{3.5}$$

Eventually, we can define the loss rate per flow loss and load traffic per flow load

$$loss_i = \frac{total\ number\ of\ packets\ from\ source\ i\ that\ are\ lost}{total\ number\ of\ lost\ packets} \tag{3.6}$$

$$load_i = \frac{total\ number\ of\ packets\ arrived\ from\ source\ i}{total\ number\ of\ packets\ arrived} \tag{3.7}$$

By relating, load, loss, and $TP_i$ , the bandwidth to different sources of traffic can be calculated by queue and scheduling management methods.

Scheduling and queue administration calculations are crucial parts of switch functionalities. Switches use planning calculations to choose how and when bundles are served. Switches utilize queue administration calculations to focus when and which parcels ought to be dropped from the support. The objective of great planning and queue oversee plans is to assign transfer speed honestly among distinctive movement sources that may have diverse administration prerequisites, while boosting administration utilization.

## 3.4 Scheduling and Queuing Management Schemes

The following are the Scheduling and Queuing management schemes.

- FIFO/Drop Tail
- Random early drop (RED)
- Fair queuing (FQ)
- Stochastic fair queuing (SFQ)
- Deficit round robin (DRR)

### 3.4.1 FIFO / Droptail

The mixing of first-in- first-out (FIFO) arranging and Droptail queue organization is extensively used inside the present framework switches because of its easiness. With FIFO, packs are served at the appeal for that they are acknowledged. With Droptail, if the pad is full when a pack arrives, the approaching package is dropped.

### 3.4.2 Random Early Drop (RED)

Random early drop (RED) is a queue organization contrive that screens and controls pad inhabitance. RED finds blockage by watching the ordinary pad size of the switch. Exactly when the typical help size is greater than as far as possible month, however lower than the second edge math, the approaching groups are dropped with probability Pa, which manufactures straightly as the ordinary help size developments. Exactly when the typical support size surpasses as far as possible math, the switch drops erratically picked packages from inside the pad with probability one. RED has two key objectives: one is nicely proper the effects of obstructing general development sources heading over the granted framework limit (as a delayed consequence of the subjective package drop); and exchange is to make a stopping up avoidance framework by dropping packages when blockage is quick approaching (as an eventual outcome of right on time bundle drop) as a methodology to instruct development sources the certainty regarding stopping up before stopping up truly happens. The early drop action serves as a negative conclusion sign to the development sources and stopping up could be avoided if movement sources diminish their time in activity.

### 3.4.3 Fair Queuing (FQ)

Reasonable queuing (FQ) was unique Nagle's FQ calculation first Partitions the switch support into sub-queues, one for each one approaching movement source (for every stream Queuing). At that point the switch serves parcels in the round-robin design (parcel by-bundle Round-robin planning). Nagle's FQ calculations, then again, except the bundle size is Consistent, and in this way it neglects to give throughput honesty when bundles have diversified Sizes. An enhanced adaptation of FQ calculation that comprehends the defects in

Nagle's FQ calculation (starting here we utilize FQ to allude to this calculation and Nagle's calculation to allude to Nagle's FQ calculation). This FQ Calculation utilizes the same for every stream queuing system, however, rather than the parcel by packet Round-robin booking, it approximates the perfect bit-by-bit-round-robin Booking keeping in mind the end goal to attain throughput decency under all conditions.

### 3.4.4 Stochastic Fair Queuing (SFQ)

Stochastic fair queuing (SFQ) was proposed by to address the in efficiencies of Nagle's calculation, where the amount of sub-queues must be equivalent to the Number of activity sources. Since the amount of activity sources could be substantial and not all activity sources are dynamic in the meantime, Nagle's is wasteful and has high Computational multifaceted nature. SFQ utilization hashing, which has considerably less computational Multifaceted nature than Nagle's calculation, to guide bundles into relating queues and the aggregate number of queues just must be bigger than the aggregate number of dynamic streams. The Throughput reasonableness of SFQ is stochastic; that is, bundles from diverse movement sources will impact into the same sub-queue when the amount of dynamic streams is bigger than the Number of apportioning subs-queues. The likelihood of such injustice because of sub-queue The crash might be minimized by setting the hashing file to be a little numerous of the Number of dynamic streams. SFQ, in any case, is still a bundle by-parcel round-robin Planning plan and hence it inherits the same imperfections in Nagle's calculation. The other Key usefulness of SFQ is its bundle dropping strategy. At the point when the cradle is full, SFQ Drops bundles from the longest sub-queue (longest sub-queue parcel drop arrangement) by dropping the arriving bundles.

### 3.4.5 Deficit Round Robin (DRR)

Deficit round robin (DRR) booking calculation is used for the rough the execution of FQ utilizing a less perplexing computational structure. DRR utilizes the same hashing component and longest sub-queue parcel drop approach as in SFQ. DRR serves sub-queues in the round-robin design. For every sub queue, a deficiency counter (in bytes) is allotted. In each one round of administration, the shortfall counter is augmented by a quantum (in bytes). Each one sub-queue, when served, is permitted to send its parcels one by one if the bundle size is more modest than the shortage counter. The shortage counter is decremented by the bundle measure after a parcel is sent. At the point when the shortage counter is drained, the DRR scheduler moves to the following sub-queue.

## 3.5 Queuing Delay Model

To deliver the packet from source to destination the average delay is required which is the important performance measure for the network. In addition, delay concerns high impact on the selection and performance of network algorithms, for example flow control and routing. For these causes, it is essential to recognize the behavior and contrivance of delay, and the way in which it depends on the features of the network.

The preliminary procedural structure for evaluating delay in the network is Queuing theory. Its utilization frequently obliges streamlining presumptions since, sadly, more sensible suppositions make significant examination to a great degree of troublesome. For this reason, it is at times difficult to get precise quantitative postponement forecasts on the premise of queuing models. By and by, these models regularly give a premise for satisfactory deferral estimates, and additionally significant qualitative results and advantageous bits of knowledge.

Here we will have our look at delay of the packet amongst the subnet communication. Every link in the subnet is navigated by the packet, whose delay is the total of delays.

There are four constituents of separate delay in links such as

I. The processing delay between the time the packet is rightly accepted at the head hub of the connection and the time the packet is doled out to a friendly connection queue for broadcast.
II. The time between the packet which is assigned to a queue for broadcast and the time its starts being broadcasted is called queuing delay. Within this period, the other packets which are in the broadcast are broadcasted and packet will until it is done.
III. The period between the initial and final bits of packet are broadcasted is the transmission delay.
IV. The duration between the final bit is broadcasted at link of head node to the duration it is accepted at the tail node is the propagation delay which is proportionate to the normal length across the source and destination which is generally minor except in the case of a link satellite.

### 3.6 Delay Calculation

In a fiber when a light is propagated along it, a delay is occurred per unit length which is due to the material that the fiber is made off. This delay is called dependent delay. The delay $D_m(i, j)$ per unit length of a link *(i, j)* which can be expressed as

$$D_m(\text{i, j}) = m_a + m_b * \lambda_l^2(\text{i, j}) + m_c * \lambda_l^{-2}(\text{i, j}) \tag{3.8}$$

Where $m_a$, $m_b$ and $m_c$ are material constants of fiber. $\lambda_l(i, j)$ is the $l^{th}$ wavelength on link (i, j). The overall delay *D* occurred in the link *(i, j)* with length *L(i, j)* can be expressed as

$$D_o(\text{i, j}) = L(\text{i, j}) * D_m(\text{i, j}) \tag{3.9}$$

The delay dependent, $D^k(s, d)$ si the total of all individual link delays suffered by a $k^{th}$ connection, which can be expressed as

$$D^k(\text{s,d}) = \sum_{(\text{i,j}) \in (\text{s,d})} D_o(\text{i, j}) \tag{3.10}$$

The above expressed equations are used to calculate the delay in the fiber material dependent Optical networks when a light is propagated through it in a wavelength form.

## 3.7 Blocking Probability

Blocking probability is defined as the time fraction of the request of packet which is deprived of because of all routers are hectic. For a given network, blocking probability is generally considered. Desired value of this is 2%. Blocking probability of group of packets is 0.05 which means that they are all together hectic at time of 5%.

A router which is having only one link (assume) where packet is travelling through it which is blocked, then its probability is given as

$$B_R = q_j(0) \tag{3.11}$$

Probability that the j is the link where there is no wavelength which is of idle.

The measurement of blocking probability will help us to know about the nature of methodology at several connections. It gives us the number of connections blocked for a particular connection. We make an assumption that the total number of requested connections as $TC_r(k, s, d)$ and the total number of connections blocked $TC_b(k, s, d)$ for $K$ number of connections. The blocking probability $B_p(k, s, d)$ can be defined as

$$B_p(k,\ s\ ,\ d) = \frac{TC_b(k,\ s,\ d)}{TC_r(k,\ s,\ d)} * 100 \tag{3.12}$$

From the above expression we can estimate the number connections that a blocked for a *k*-connections are requested.

# Chapter 4

# Network Design and Simulation

## 4.1 Network Design

In the fig 2.2, we have shown the general block diagram of communication of wireless optical link. The signal is transmitted by the optical transmitter which contains data or information in the form of wavelengths over the wireless channel. We consider the routers are established in a range of area of meters distance from routers to routers where the data transmission is carried via routers.

## 4.2 Network Topology

Topology of the network is shown in the figure 4.2 .We have considered the 10 nodes and 16 links in the network which are at random distance. Here we considered the nodes as nothing but the optical wireless routers where the transmission of data is carried. The data transmitted over the signal. We considered the signal in the wavelength form. Different wavelengths are selected Which are of 1230nm, 1250nm, 1270nm, 1290nm, 1320nm, 1340nm, 1350nm and 1360nm. We fixed the source as node 2 and destination as node 9 for data transmission and QoS of the transmission are calculated by simulation.

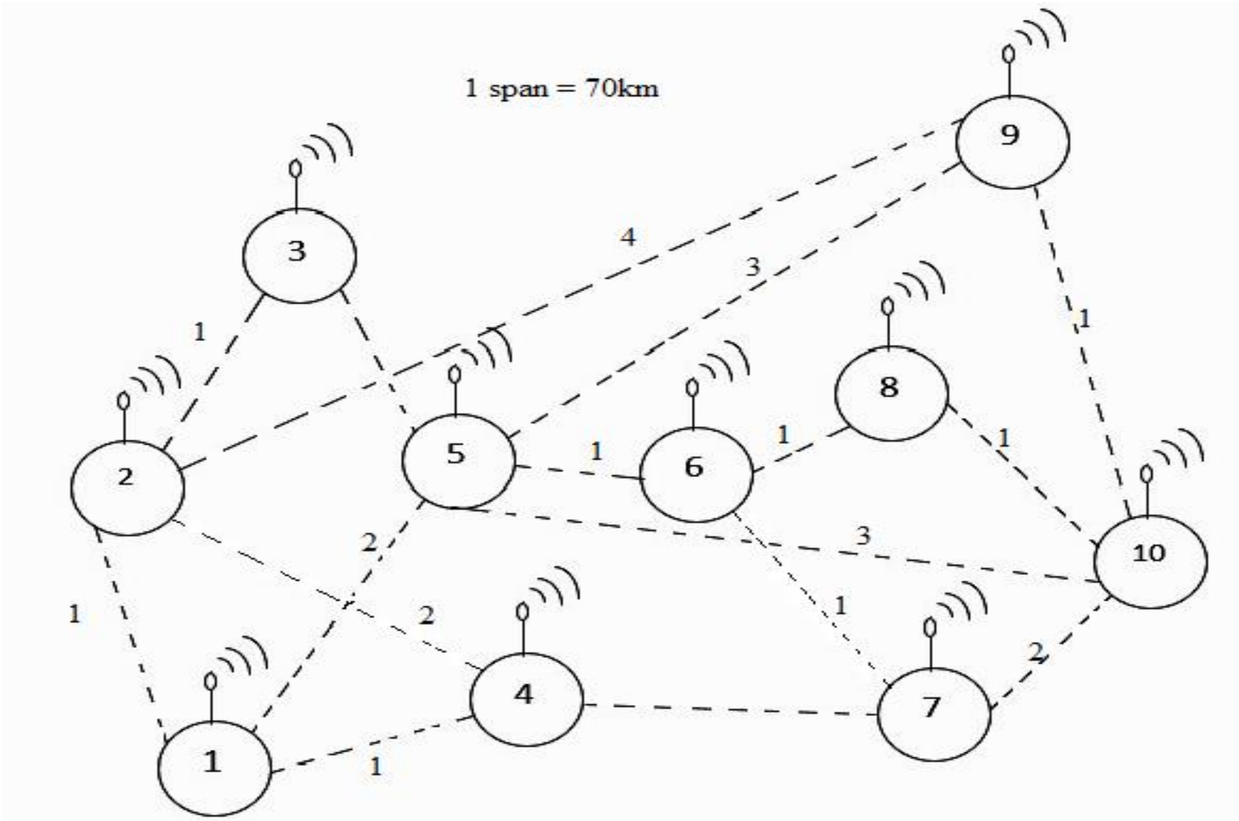


**Fig 4. 1 : Topology of the Network**

## 4.3 Simulation for QoS parameters

As we have already discussed the different parameters of QoS in chapter 3 in which delay is the major factor for service requirement. For that purpose we have considered delay as the major problem and simulation is done for it. The shortest path for the above network topology of all possible paths are calculated for fixed source and destination. Using the algorithm we have find path and for that path the delay for different wavelengths has been simulated. For simulating the delay, we have used queuing in model concept in which little theorem was proposed has gone through that concept for delay.

The following algorithm for proposed to estimate the delay of the network topology and to find the minimum path delay of the feasible paths.

**Algorithm proposed**:

**Path State Advertisement** (PSA):

For each path k, advertise current connection request.

**Link State Prediction** (LSP):

For each link (i, j) estimate delay $D_{pk}$

$$i.e., D_{pk} = \sum_{(i,j)\in p_k} D^k(i,j) \quad where\ k \in N \tag{4.1}$$

**Path Computation:**

Compute $N$ possible paths from source to destination.

Derive a set of paths $F$ that satisfy the delay requirement of the packet.

**Admission Control:**

Admit a new connection request in the mesh only if delay requirement $D_{pk}$ satisfies the minimum delay among the feasible paths F.

$$Min_{p_r \in F}(D_{P_r}) \leq D_{req} \tag{4.2}$$

## 4.4 Simulation Results and Discussion

For the network topology shown above in the figure 4.1 simulation has been done using the proposed algorithm with different source-destination pairs of the network where the multiple wavelengths are sent through it.

The proposed algorithm determines the best path from all possible paths between source-destination pair which has minimum delay. The path delays is calculated for different wavelengths. A source-destination (s, d) pair of (2, 9) is chosen and their corresponding path delays are calculated for different wavelengths. For this pair 29 possible paths are obtained in which one path has minimum delay. Table 2 summarizes the path delays for all possible paths by considering different wavelengths for the source-destination pair (2, 9). The blocking probability for different connection requests are also calculated for the source-destination pair (2, 9) which is shown in table 3. Figure 4.2 to 4.9 depicts path delays and blocking probability for each wavelength individually. The comparison for path delays with respect to number of possible paths and blocking probability with respect to number of connection requests for all wavelengths is shown in figure 4.10 & 4.11.

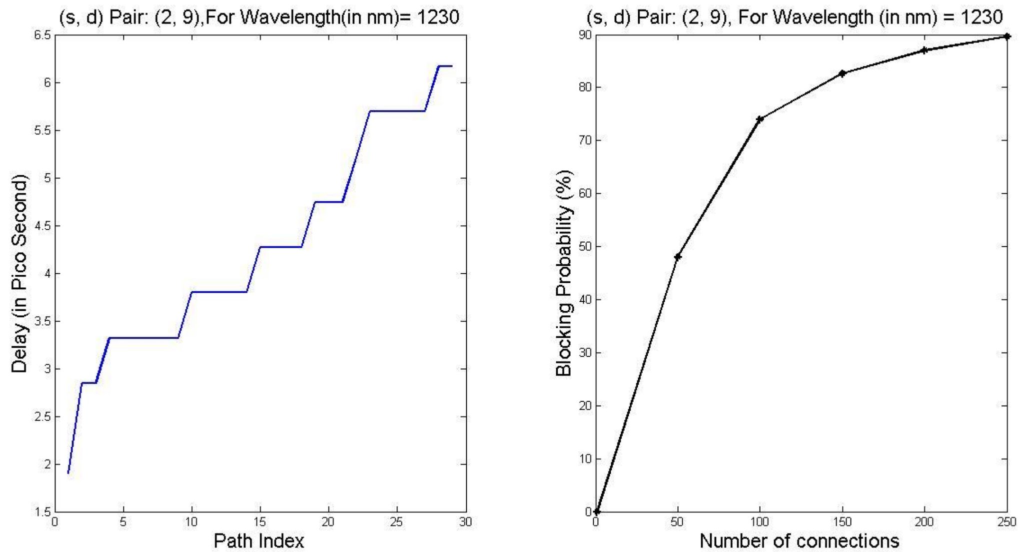


**Fig 4. 2: Path delay and blocking probability for (s, d) pair (2, 9) using wavelength 1230nm.**

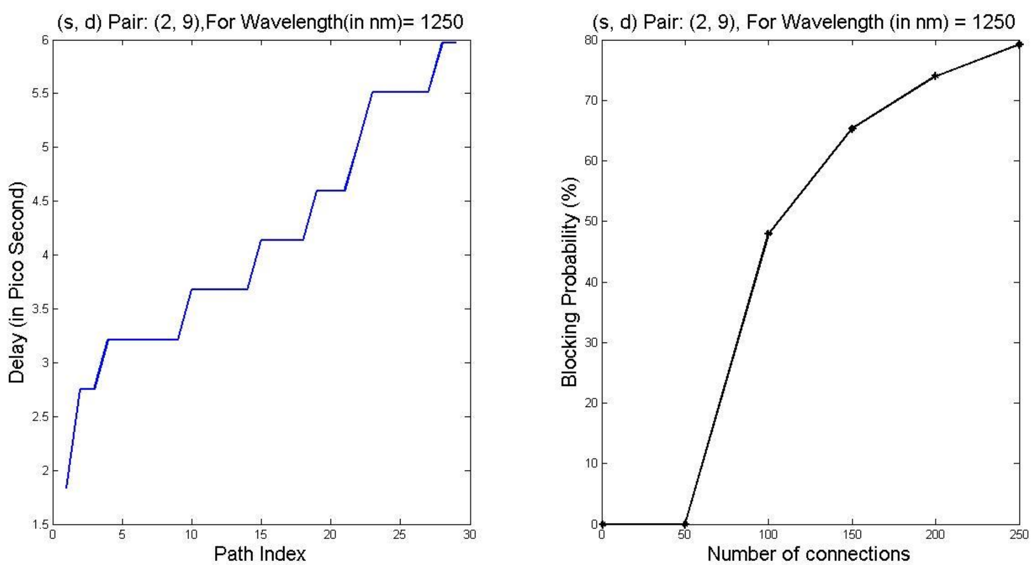


**Fig 4. 3 Path delay and blocking probability for (s, d) pair (2, 9) using wavelength 1250nm.**

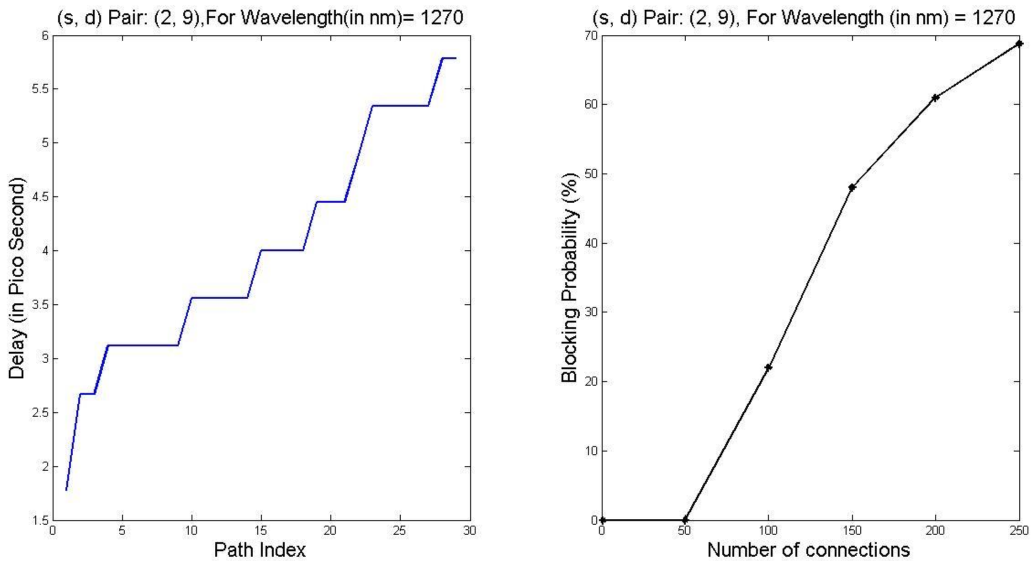


**Fig 4. 4: Path delay and blocking probability for (s, d) pair (2, 9) using wavelength 1270nm.**

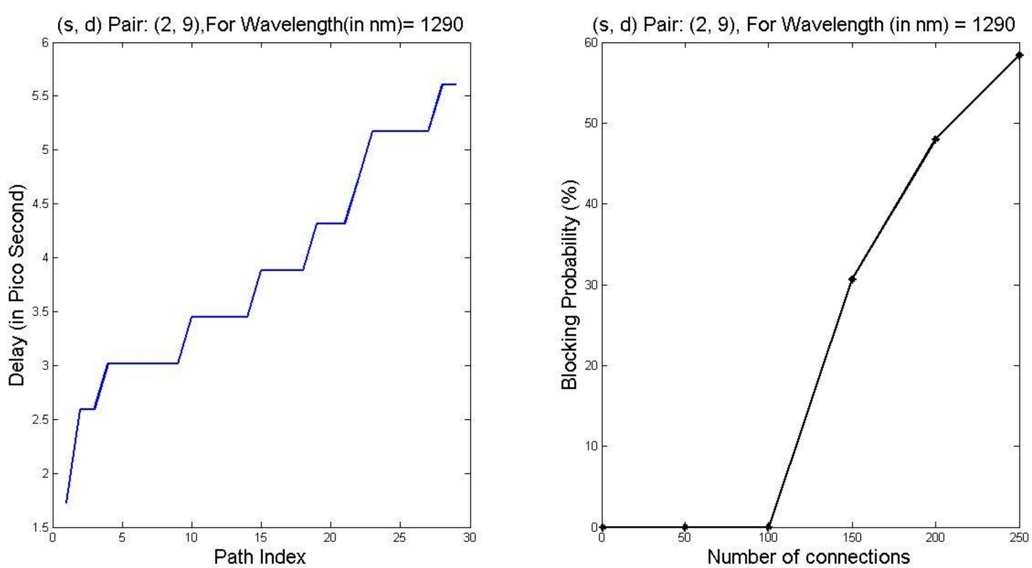


**Fig 4. 5: Path delay and blocking probability for (s, d) pair (2, 9) using wavelength 1290nm.**

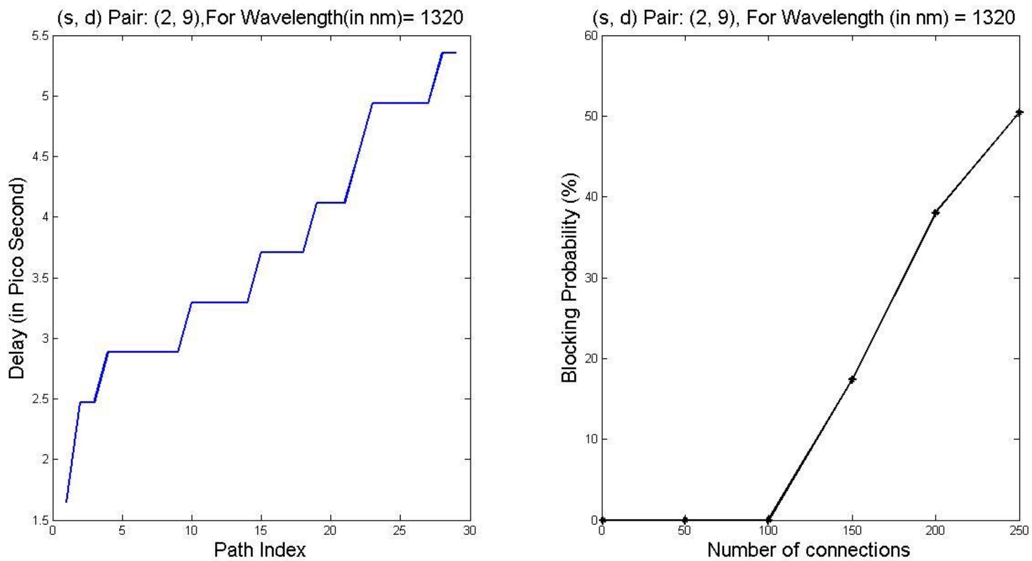


**Fig 4. 6: Path delay and blocking probability for (s, d) pair (2, 9) using wavelength 1320nm.**

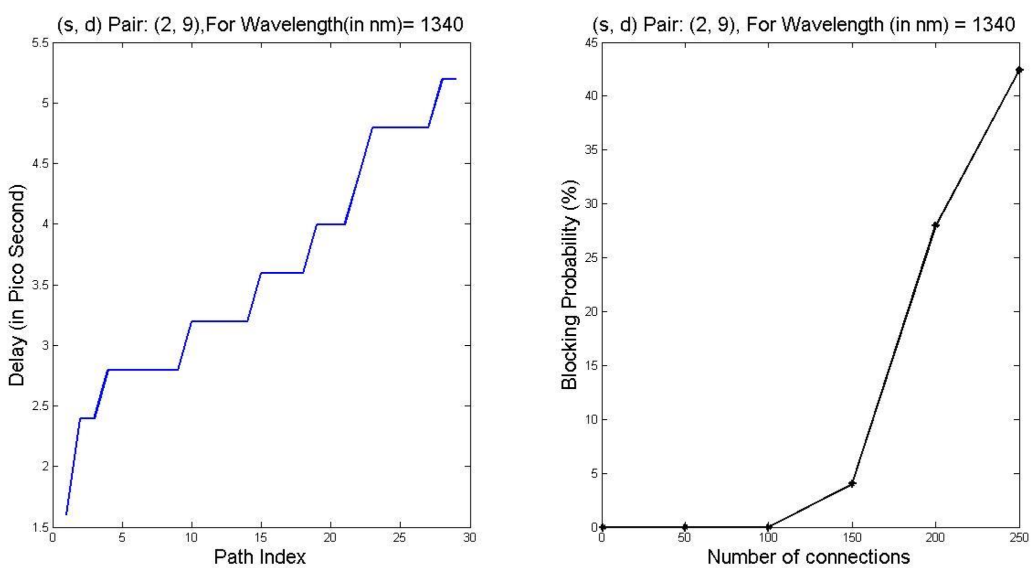


**Fig 4. 7: Path delay and blocking probability for (s, d) pair (2, 9) using wavelength 1340nm.**

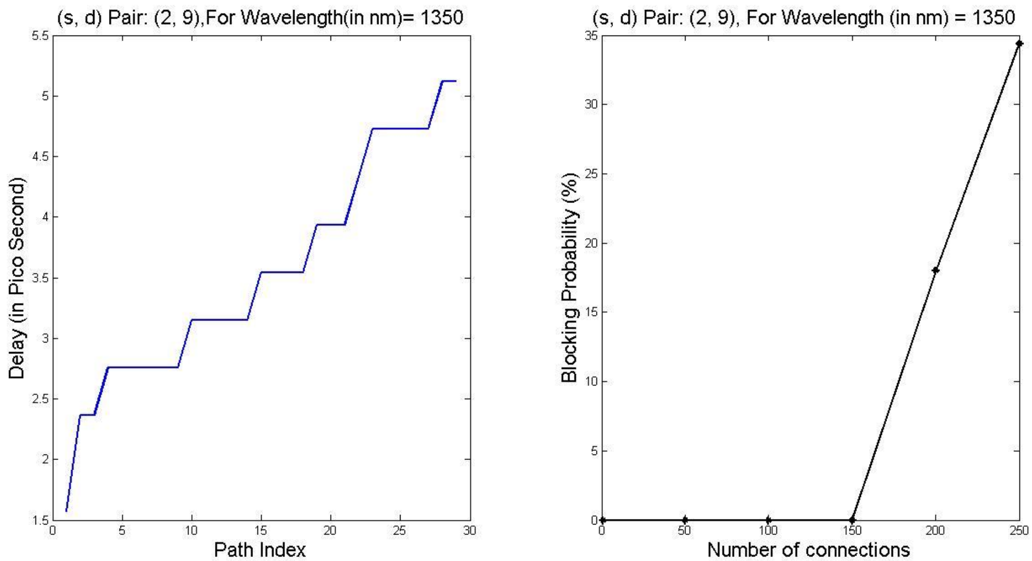


**Fig 4. 8: Path delay and blocking probability for (s, d) pair (2, 9) using wavelength 1350nm.**

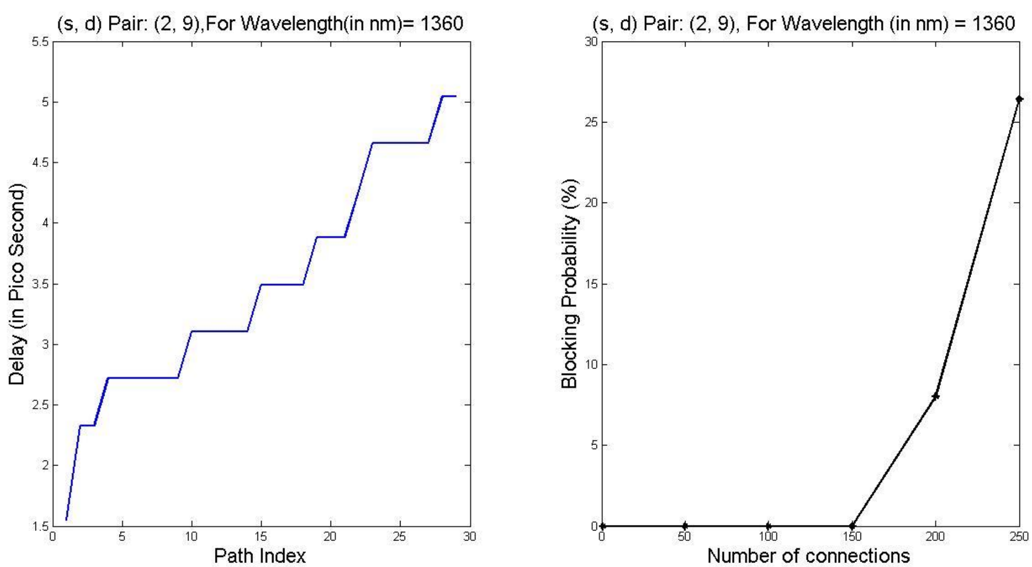


**Fig 4. 9: Path delay and blocking probability for (s, d) pair (2, 9) using wavelength 1360nm.**

**Table 2: Delay values for different wavelengths for all possible paths for (s, d) pair (2, 9)**

| Wavelength (in nm) / path index | 1230 | 1250 | 1270 | 1290 | 1320 | 1340 | 1350 | 1360 |
|---|---|---|---|---|---|---|---|---|
| 1 | 1.8970 | 1.8368 | 1.7794 | 1.7247 | 1.6472 | 1.5984 | 1.5748 | 1.5517 |
| 2 | 2.8455 | 2.7552 | 2.6691 | 2.5870 | 2.4707 | 2.3975 | 2.3621 | 2.3275 |
| 3 | 2.8455 | 2.7552 | 2.6691 | 2.5870 | 2.4707 | 2.3975 | 2.3621 | 2.3275 |
| 4 | 3.3198 | 3.2144 | 3.1140 | 3.0181 | 2.8825 | 2.7971 | 2.7558 | 2.7155 |
| 5 | 3.3198 | 3.2144 | 3.1140 | 3.0181 | 2.8825 | 2.7971 | 2.7558 | 2.7155 |
| 6 | 3.3198 | 3.2144 | 3.1140 | 3.0181 | 2.8825 | 2.7971 | 2.7558 | 2.7155 |
| 7 | 3.3198 | 3.2144 | 3.1140 | 3.0181 | 2.8825 | 2.7971 | 2.7558 | 2.7155 |
| 8 | 3.3198 | 3.2144 | 3.1140 | 3.0181 | 2.8825 | 2.7971 | 2.7558 | 2.7155 |
| 9 | 3.3198 | 3.2144 | 3.1140 | 3.0181 | 2.8825 | 2.7971 | 2.7558 | 2.7155 |
| 10 | 3.7940 | 3.6736 | 3.5588 | 3.4493 | 3.2943 | 3.1967 | 3.1495 | 3.1034 |
| 11 | 3.7940 | 3.6736 | 3.5588 | 3.4493 | 3.2943 | 3.1967 | 3.1495 | 3.1034 |
| 12 | 3.7940 | 3.6736 | 3.5588 | 3.4493 | 3.2943 | 3.1967 | 3.1495 | 3.1034 |
| 13 | 3.7940 | 3.6736 | 3.5588 | 3.4493 | 3.2943 | 3.1967 | 3.1495 | 3.1034 |
| 14 | 3.7940 | 3.6736 | 3.5588 | 3.4493 | 3.2943 | 3.1967 | 3.1495 | 3.1034 |
| 15 | 4.2683 | 4.1328 | 4.0037 | 3.8805 | 3.7061 | 3.5963 | 3.5432 | 3.4913 |
| 16 | 4.2683 | 4.1328 | 4.0037 | 3.8805 | 3.7061 | 3.5963 | 3.5432 | 3.4913 |
| 17 | 4.2683 | 4.1328 | 4.0037 | 3.8805 | 3.7061 | 3.5963 | 3.5432 | 3.4913 |
| 18 | 4.2683 | 4.1328 | 4.0037 | 3.8805 | 3.7061 | 3.5963 | 3.5432 | 3.4913 |
| 49 | 4.7425 | 4.5920 | 4.4485 | 4.3116 | 4.1179 | 3.9959 | 3.9369 | 3.8792 |
| 20 | 4.7425 | 4.5920 | 4.4485 | 4.3116 | 4.1179 | 3.9959 | 3.9369 | 3.8792 |
| 21 | 4.7425 | 4.5920 | 4.4485 | 4.3116 | 4.1179 | 3.9959 | 3.9369 | 3.8792 |
| 22 | 5.2168 | 5.0512 | 4.8934 | 4.7428 | 4.5297 | 4.3955 | 4.3306 | 4.2671 |
| 23 | 5.6911 | 5.5104 | 5.3382 | 5.1740 | 4.9415 | 4.7951 | 4.7243 | 4.6551 |
| 24 | 5.6911 | 5.5104 | 5.3382 | 5.1740 | 4.9415 | 4.7951 | 4.7243 | 4.6551 |
| 25 | 5.6911 | 5.5104 | 5.3382 | 5.1740 | 4.9415 | 4.7951 | 4.7243 | 4.6551 |
| 26 | 5.6911 | 5.5104 | 5.3382 | 5.1740 | 4.9415 | 4.7951 | 4.7243 | 4.6551 |
| 27 | 5.6911 | 5.5104 | 5.3382 | 5.1740 | 4.9415 | 4.7951 | 4.7243 | 4.6551 |
| 28 | 6.1653 | 5.9696 | 5.7831 | 5.6051 | 5.3532 | 5.1946 | 5.1180 | 5.0430 |
| 29 | 6.1653 | 5.9696 | 5.7831 | 5.6051 | 5.3532 | 5.1946 | 5.1180 | 5.0430 |

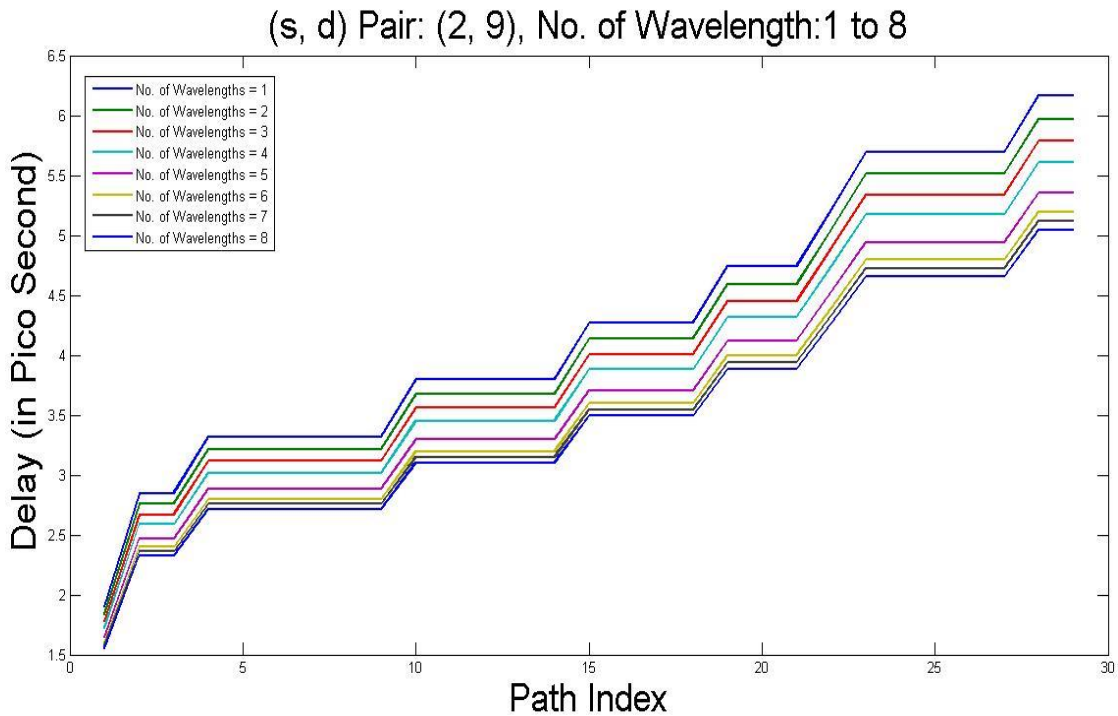


**Fig 4. 10: Delay vs Path Index for (s, d) pair (2, 9)**

**Table 3: Blocking Probability vs No: of Connections for (s, d) pair (2, 9)**

| Wavelength (in nm) / No of connections | 1 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 1230 | 0 | 48 | 74 | 82.66667 | 87 | 89.6 |
| 1250 | 0 | 0 | 48 | 65.33333 | 74 | 79.2 |
| 1270 | 0 | 0 | 22 | 48 | 61 | 68.8 |
| 1290 | 0 | 0 | 0 | 30.66667 | 48 | 58.4 |
| 1320 | 0 | 0 | 0 | 17.33333 | 38 | 50.4 |
| 1340 | 0 | 0 | 0 | 4 | 28 | 42.4 |
| 1350 | 0 | 0 | 0 | 0 | 18 | 34.4 |
| 1360 | 0 | 0 | 0 | 0 | 8 | 26.4 |

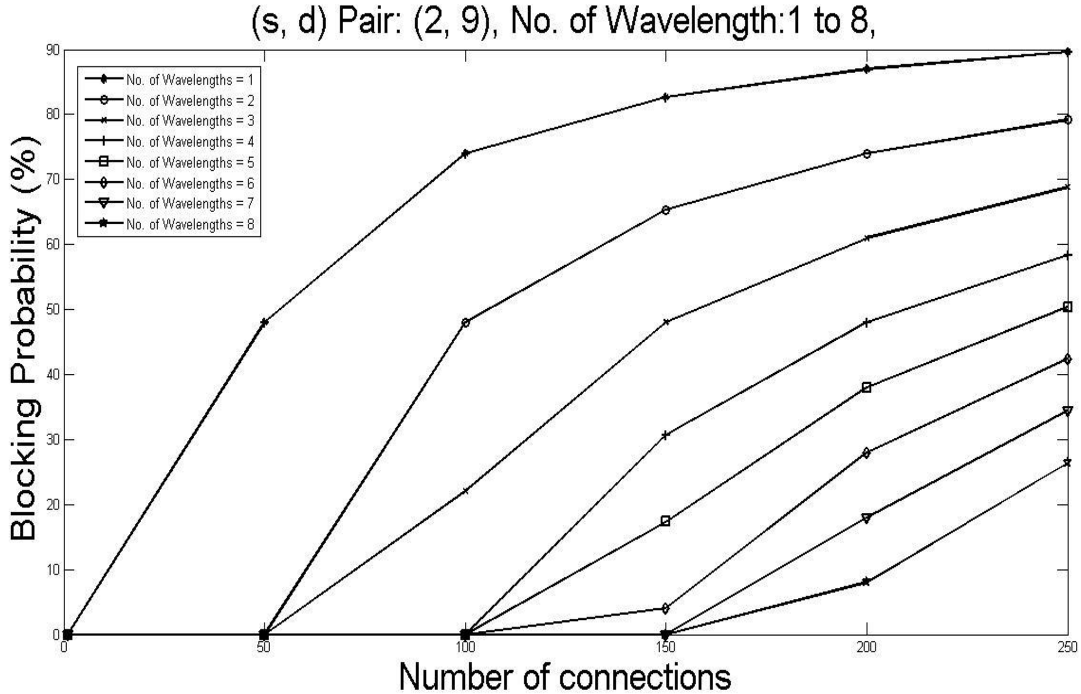


**Fig 4. 11: Blocking Probability vs No: of Connections for (s, d) pair (2, 9)**

Similarly, source-destination pairs (1, 5) and (7, 10) are chosen and their corresponding path delays and blocking probabilities for all wavelengths are calculated which are shown in tables 4 to 7 and figures 4.12 to 4.15.

**Table 4: Delay values for different wavelengths for all possible paths for (s, d) pair (1, 5)**

| Wavelength (in nm) / path index | 1230 | 1250 | 1270 | 1290 | 1320 | 1340 | 1350 | 1360 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.948509 | 0.9184 | 0.889702 | 0.862328 | 0.823577 | 0.799176 | 0.78738 | 0.775843 |
| 2 | 1.897019 | 1.8368 | 1.779404 | 1.724656 | 1.647153 | 1.598352 | 1.57476 | 1.551687 |
| 3 | 2.371274 | 2.296 | 2.224254 | 2.15582 | 2.058942 | 1.997939 | 1.96845 | 1.939609 |
| 4 | 2.845528 | 2.7552 | 2.669105 | 2.586984 | 2.47073 | 2.397527 | 2.36214 | 2.32753 |
| 5 | 3.319783 | 3.2144 | 3.113956 | 3.018148 | 2.882518 | 2.797115 | 2.75583 | 2.715452 |
| 6 | 3.794038 | 3.6736 | 3.558807 | 3.449312 | 3.294307 | 3.196703 | 3.14952 | 3.103374 |
| 7 | 3.794038 | 3.6736 | 3.558807 | 3.449312 | 3.294307 | 3.196703 | 3.14952 | 3.103374 |
| 8 | 3.794038 | 3.6736 | 3.558807 | 3.449312 | 3.294307 | 3.196703 | 3.14952 | 3.103374 |
| 9 | 4.268293 | 4.1328 | 4.003658 | 3.880476 | 3.706095 | 3.596291 | 3.54321 | 3.491295 |
| 10 | 4.268293 | 4.1328 | 4.003658 | 3.880476 | 3.706095 | 3.596291 | 3.54321 | 3.491295 |
| 11 | 4.268293 | 4.1328 | 4.003658 | 3.880476 | 3.706095 | 3.596291 | 3.54321 | 3.491295 |
| 12 | 4.268293 | 4.1328 | 4.003658 | 3.880476 | 3.706095 | 3.596291 | 3.54321 | 3.491295 |
| 13 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 14 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 15 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 16 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 17 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 18 | 5.216802 | 5.0512 | 4.89336 | 4.742804 | 4.529672 | 4.395467 | 4.33059 | 4.267139 |
| 49 | 5.216802 | 5.0512 | 4.89336 | 4.742804 | 4.529672 | 4.395467 | 4.33059 | 4.267139 |
| 20 | 5.216802 | 5.0512 | 4.89336 | 4.742804 | 4.529672 | 4.395467 | 4.33059 | 4.267139 |
| 21 | 5.216802 | 5.0512 | 4.89336 | 4.742804 | 4.529672 | 4.395467 | 4.33059 | 4.267139 |
| 22 | 5.691057 | 5.5104 | 5.338211 | 5.173968 | 4.94146 | 4.795055 | 4.72428 | 4.655061 |
| 23 | 5.691057 | 5.5104 | 5.338211 | 5.173968 | 4.94146 | 4.795055 | 4.72428 | 4.655061 |
| 24 | 6.165312 | 5.9696 | 5.783062 | 5.605132 | 5.353248 | 5.194642 | 5.11797 | 5.042982 |
| 25 | 6.639566 | 6.4288 | 6.227912 | 6.036296 | 5.765037 | 5.59423 | 5.51166 | 5.430904 |

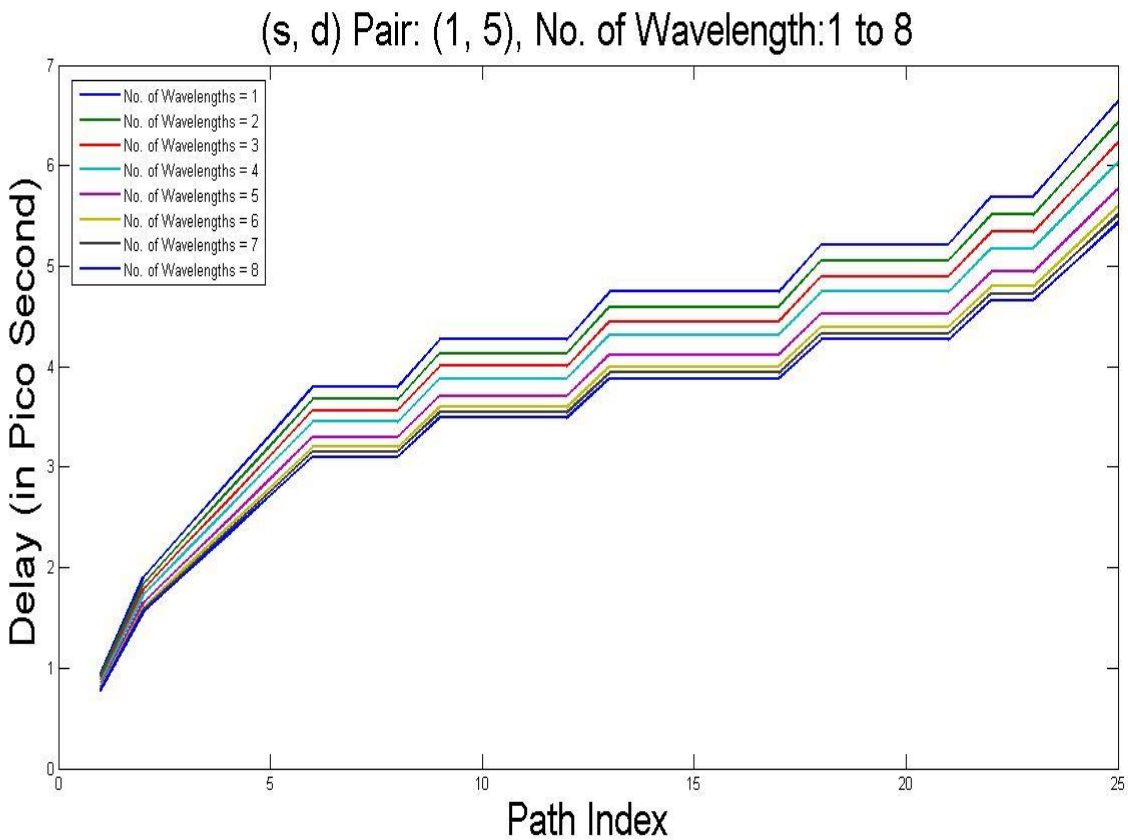


**Fig 4. 12: Delay vs Path Index for (s, d) pair (1, 5)**

**Table 5: Blocking Probability vs No: of Connections for (s, d) pair (1, 5)**

| Wavelength (in nm) / No of connections | 1 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 1230 | 0 | 58 | 79 | 86 | 89.5 | 91.6 |
| 1250 | 0 | 16 | 58 | 72 | 79 | 83.2 |
| 1270 | 0 | 0 | 37 | 58 | 68.5 | 74.8 |
| 1290 | 0 | 0 | 16 | 44 | 58 | 66.4 |
| 1320 | 0 | 0 | 0 | 30.66667 | 48 | 58.4 |
| 1340 | 0 | 0 | 0 | 17.33333 | 38 | 50.4 |
| 1350 | 0 | 0 | 0 | 4 | 28 | 42.4 |
| 1360 | 0 | 0 | 0 | 0 | 18 | 34.4 |

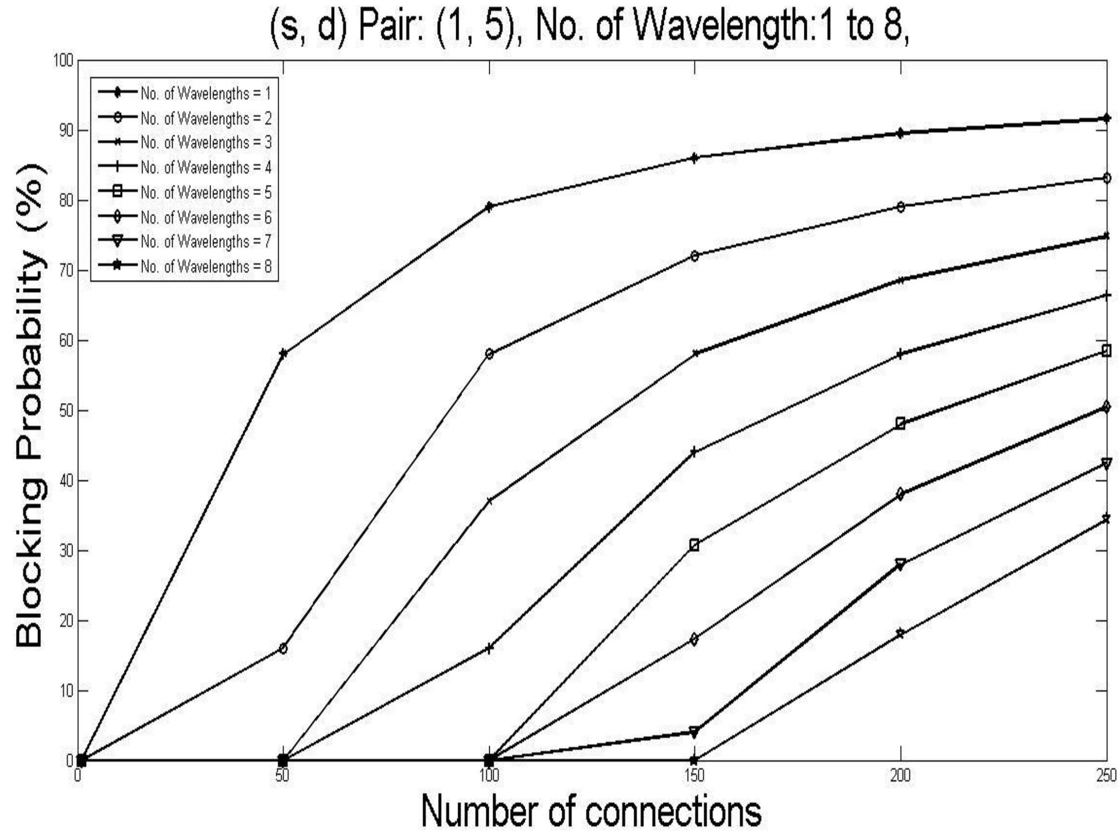


**Fig 4. 13: Blocking Probability vs No: of Connections for (s, d) pair (1, 5)**

**Table 6: Delay values for different wavelengths for all possible paths for (s, d) pair (7, 10)**

| Wavelength (in nm) / path index | 1230 | 1250 | 1270 | 1290 | 1320 | 1340 | 1350 | 1360 |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.948509 | 0.9184 | 0.889702 | 0.862328 | 0.823577 | 0.799176 | 0.78738 | 0.775843 |
| 2 | 1.422764 | 1.3776 | 1.334553 | 1.293492 | 1.235365 | 1.198764 | 1.18107 | 1.163765 |
| 3 | 2.371274 | 2.296 | 2.224254 | 2.15582 | 2.058942 | 1.997939 | 1.96845 | 1.939609 |
| 4 | 2.845528 | 2.7552 | 2.669105 | 2.586984 | 2.47073 | 2.397527 | 2.36214 | 2.32753 |
| 5 | 3.794038 | 3.6736 | 3.558807 | 3.449312 | 3.294307 | 3.196703 | 3.14952 | 3.103374 |
| 6 | 3.794038 | 3.6736 | 3.558807 | 3.449312 | 3.294307 | 3.196703 | 3.14952 | 3.103374 |
| 7 | 4.268293 | 4.1328 | 4.003658 | 3.880476 | 3.706095 | 3.596291 | 3.54321 | 3.491295 |
| 8 | 4.268293 | 4.1328 | 4.003658 | 3.880476 | 3.706095 | 3.596291 | 3.54321 | 3.491295 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9 | 4.268293 | 4.1328 | 4.003658 | 3.880476 | 3.706095 | 3.596291 | 3.54321 | 3.491295 |
| 10 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 11 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 12 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 13 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 14 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 15 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 16 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 17 | 4.742547 | 4.592 | 4.448509 | 4.31164 | 4.117883 | 3.995879 | 3.9369 | 3.879217 |
| 18 | 5.216802 | 5.0512 | 4.89336 | 4.742804 | 4.529672 | 4.395467 | 4.33059 | 4.267139 |
| 49 | 5.216802 | 5.0512 | 4.89336 | 4.742804 | 4.529672 | 4.395467 | 4.33059 | 4.267139 |
| 20 | 5.216802 | 5.0512 | 4.89336 | 4.742804 | 4.529672 | 4.395467 | 4.33059 | 4.267139 |
| 21 | 5.691057 | 5.5104 | 5.338211 | 5.173968 | 4.94146 | 4.795055 | 4.72428 | 4.655061 |
| 22 | 6.165312 | 5.9696 | 5.783062 | 5.605132 | 5.353248 | 5.194642 | 5.11797 | 5.042982 |
| 23 | 6.639566 | 6.4288 | 6.227912 | 6.036296 | 5.765037 | 5.59423 | 5.51166 | 5.430904 |
| 24 | 6.639566 | 6.4288 | 6.227912 | 6.036296 | 5.765037 | 5.59423 | 5.51166 | 5.430904 |
| 25 | 6.639566 | 6.4288 | 6.227912 | 6.036296 | 5.765037 | 5.59423 | 5.51166 | 5.430904 |
| 26 | 6.639566 | 6.4288 | 6.227912 | 6.036296 | 5.765037 | 5.59423 | 5.51166 | 5.430904 |

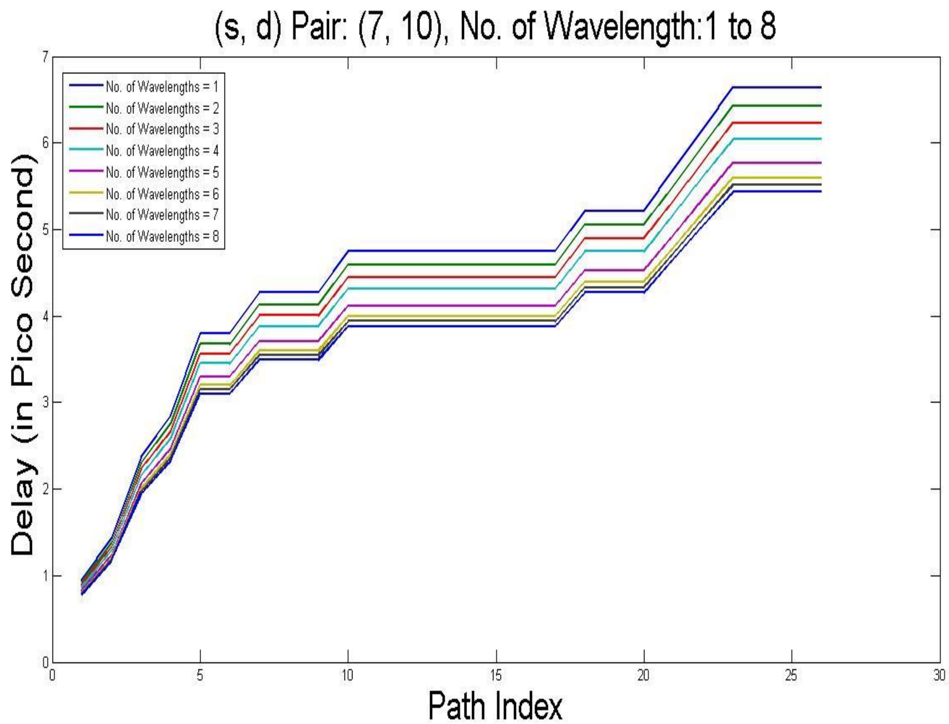


**Fig 4. 14: Delay vs Path Index for (s, d) pair (7, 10)**

**Table 7: Blocking Probability vs No: of Connections for (s, d) pair (7, 10)**

| Wavelength (in nm) / No of connections | 1 | 50 | 100 | 150 | 200 | 250 |
|---|---|---|---|---|---|---|
| 1230 | 0 | 56 | 78 | 85.33333 | 89 | 91.2 |
| 1250 | 0 | 12 | 56 | 70.66667 | 78 | 82.4 |
| 1270 | 0 | 0 | 34 | 56 | 67 | 73.6 |
| 1290 | 0 | 0 | 12 | 41.33333 | 56 | 64.8 |
| 1320 | 0 | 0 | 0 | 26.66667 | 45 | 56 |
| 1340 | 0 | 0 | 0 | 12 | 34 | 47.2 |
| 1350 | 0 | 0 | 0 | 0 | 23 | 38.4 |
| 1360 | 0 | 0 | 0 | 0 | 12 | 29.6 |

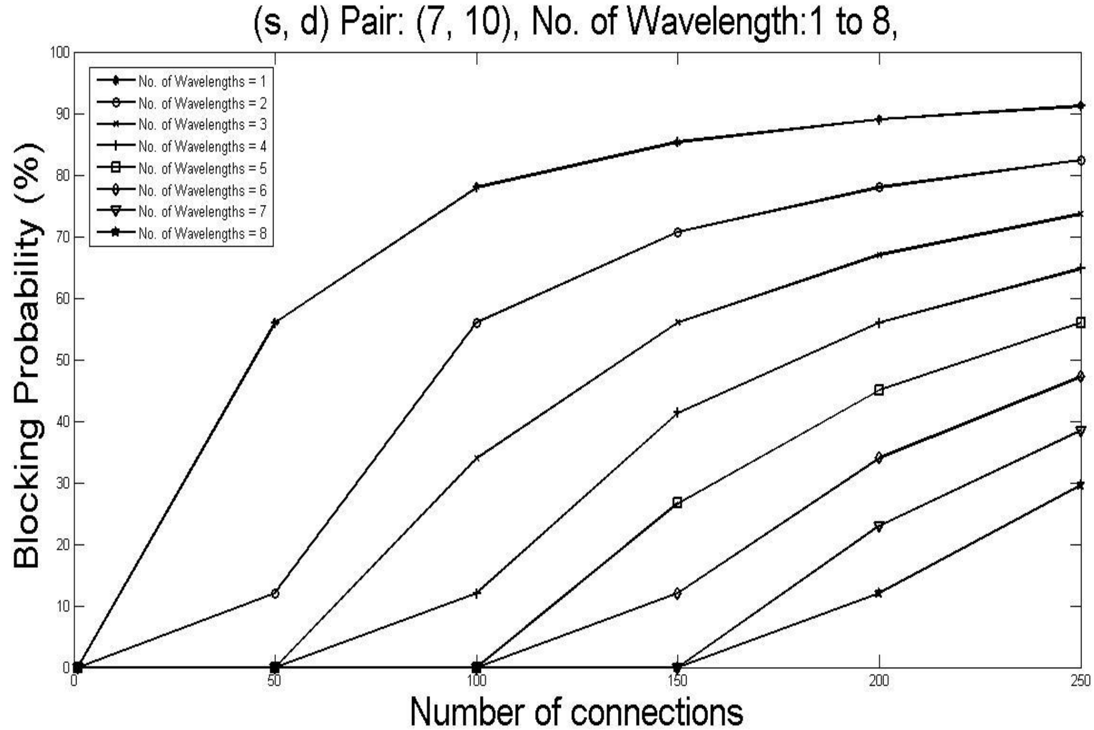


**Fig 4. 15: Blocking probability vs No: of Connections for (s, d) pair (7, 10)**

# Chapter 5
# Conclusion and Future work

## Conclusion and Future Work

We have proposed an algorithm for calculating the delay for the network topology assumed and calculated the delay with different number of wavelengths for all possible paths of different source and destination pair. Here, we mainly considered the source-destination pair as (2, 9). For this pair we calculated the delay for each wavelength in each possible paths. Number of connections for the destination from the source that is information transmitted is can be blocked for that we calculated the blocking probability for every possible path with different wavelengths. It has been observed that as the wavelength increasing, delay is decreasing gradually and also number of connections blocked are decreased. So, when number of wavelengths sent at a time decreases the delay and blocking probability of the network. Such that, multiple information can be send a time without any delay and security for the data is attained.

This project work can be extended to different other topologies of the network by considering other parameters like the fiber material made by and to multiple wireless optical networks.

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